Small Spacecraft Bus Development in the New Millennium

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Satellite development in the New Millennium will be characterized by shrinking schedules at lower cost with greater performance required. These characteristics will require, in response, innovative Program Management Styles. Organizational structures will have to be modified, roles and responsibilities of the technical leads will have to be re-invented, and relationships between the customer and suppliers will have to be fostered to maximize flexibility in the development of satellites in the New Millennium.

Introduction

The Earth Orbiter – 1 (EO-1) Satellite program implements new Program Management styles that address the constraints of Satellite development with innovative approaches to organizational structure, government and industry co-development and industry partnering. This paper will explore the Program Management techniques implemented on the EO-1 program that address schedule shrinkage and lower cost with greater performance for future Small Satellite development in the New Millennium.

This paper presents an overview of the EO-1 mission followed by a discussion of the management concept that drives the EO-1 team. The paper details some of the challenges on the EO-1 program that have been overcome largely by the institution of this management approach. Examples will be given on how the EO-1 management concept is implemented, specifically in the organization structure and how the organization structure continues to evolve to meet the changing needs of the EO-1 program.

Mission Overview

The Earth Orbiter –1 Mission is the first of the New Millennium Program Earth Orbiting missions. The main thrust of the New Millennium Program is to develop new technologies, which will enhance satellite performance in the next century. NASA Goddard Space Flight Center (GSFC) manages the mission, including satellite ground operations. The Spacecraft Bus is being developed by an industry team lead by Swales Aerospace. Litton Amecom is responsible for the Avionics suite and supports the Spacecraft Bus Integration and Test program and launch campaign.

The primary instrument on EO-1 is an Advanced Land Imager (ALI) built by a team under the leadership of MIT/Lincoln Laboratory. The ALI's fundamental mission is to advance Land Remote Sensing by using technology which reduces mass, power, and volume requirements. This technology, when implemented on a full-scale operational mission, will reduce life cycle costs significantly for future programs. More specifics on EO-1 Advanced Sensors and Instruments can be found in paper SSC98-XI-3 by Mark Perry PhD. of this conference.

In order to verify the imaging technology, EO-1 will co-fly with the Landsat 7 satellite by being launched into a sun-synchronous orbit at 705km. The descending nodal crossing time of 10:01 a.m. places EO-1 in an inclined orbit at 98.2 degrees, following the Landsat-7 and preceding EOS-AM-1 satellites. To achieve the desired orbit, EO-1 will be launched from Vandenberg Air Force Base CA using a Delta 7320 vehicle. EO-1 will be co-manifested with the Argentine satellite SAC-C. The current allocated mass for EO-1 is 529 Kg. Figures 1a and 1b show an overview of the mechanical layout of the spacecraft.

EO-1 will incorporate numerous other technologies, which will advance future Satellite missions. These new technologies are listed in Figure 1a and 1b along with an overview of the mission flow in Figure 2.

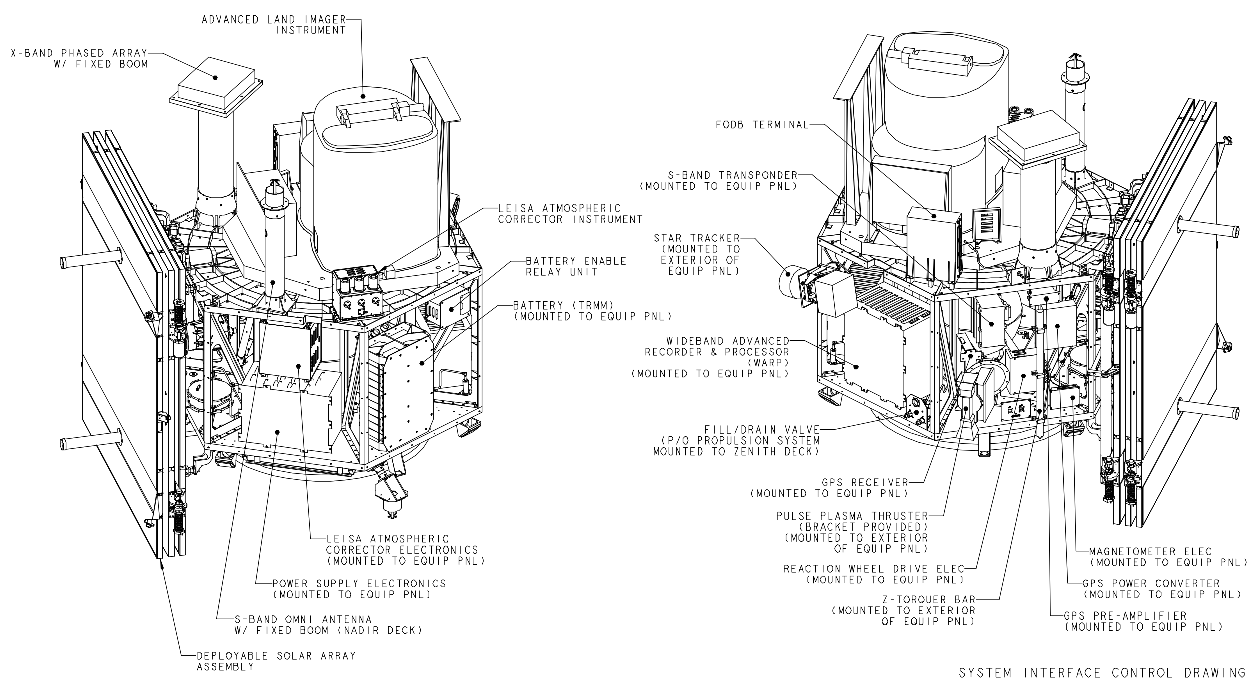


Figure 1a EO-1 Stowed Configuration Mechanical Layout (Nadir View)

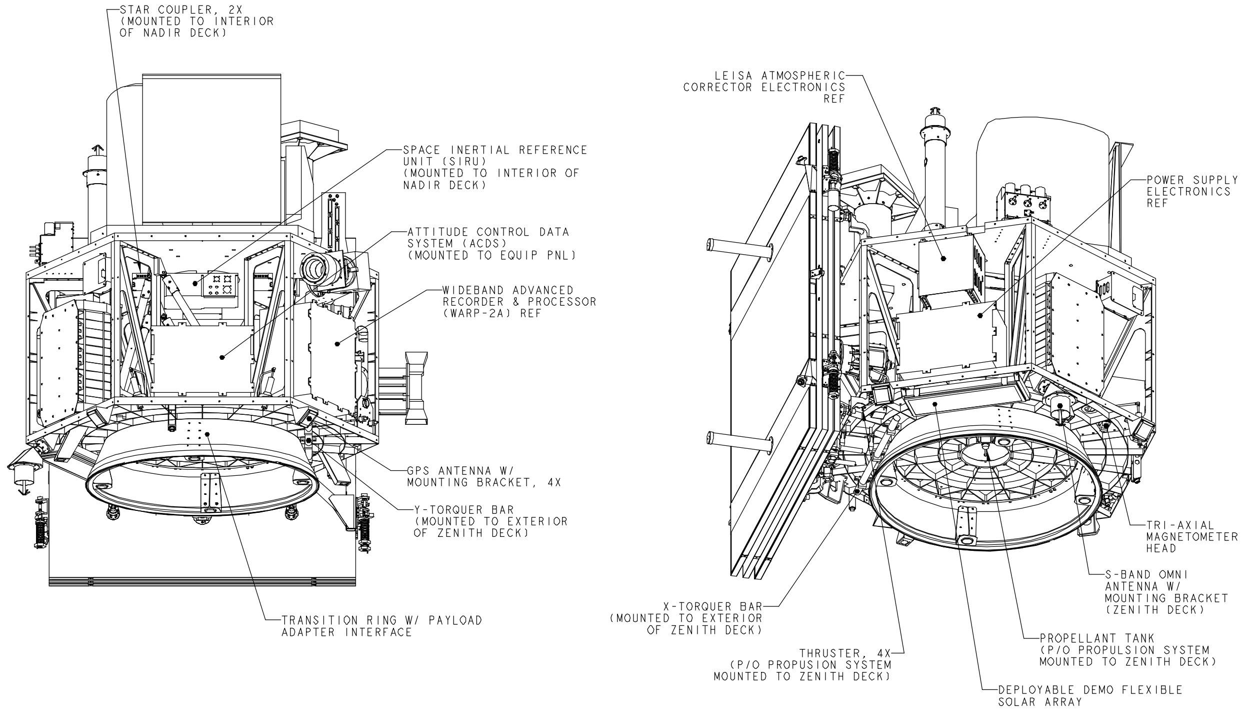


Figure 1b EO-1 Stowed Configuration Mechanical Layout (Zenith View)

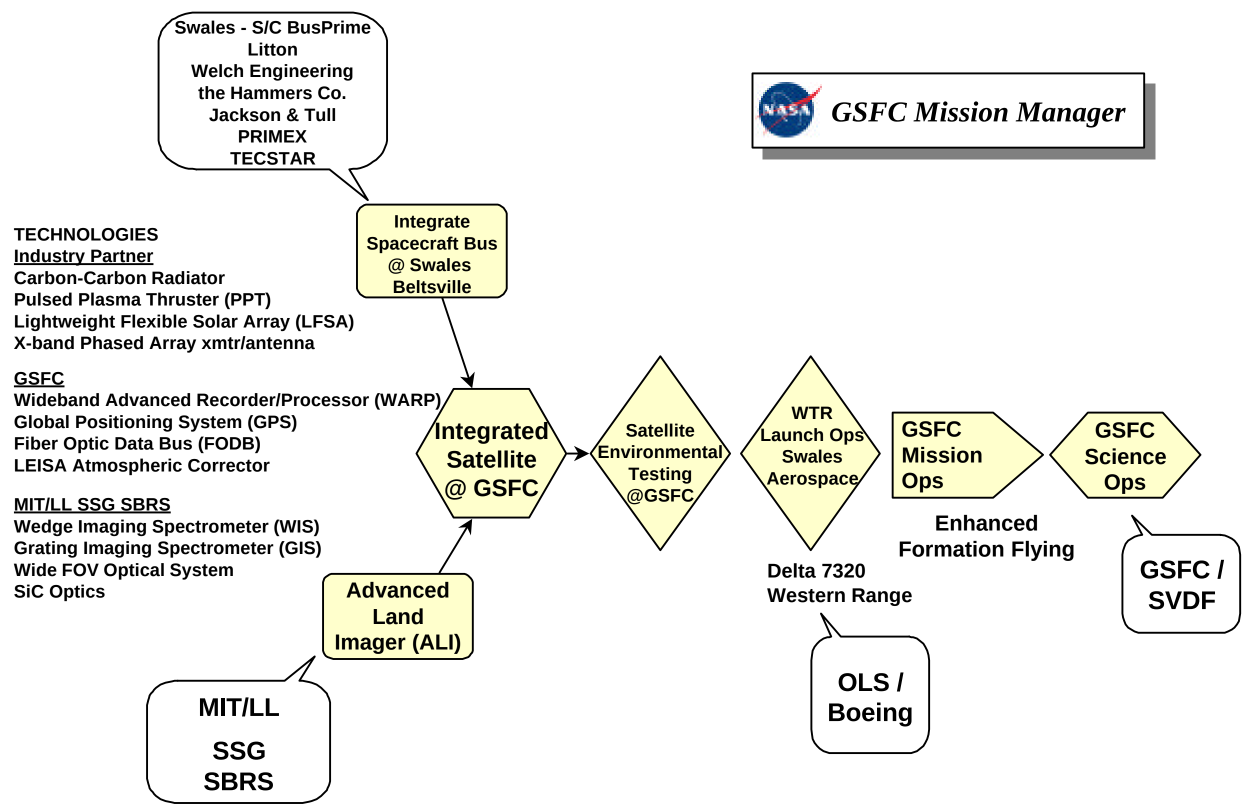


Figure 2 EO-1 Technologies and Mission Flow

EO-1 Management Concept

The EO-1 Management Concept is to bring together a team with a common vision such that the most efficient path can be taken to achieve the customer's goal. This Management Concept requires the elimination, to the maximum extent possible, of all organizational boundaries that prohibit meeting the customer's goal. The key characteristics of the EO-1 Management Concept are as follows:

- Senior management commitment to providing the resources needed to meet the requirements of the program.
- A mutual respect for each team member's capability and core competencies. This includes sharing technical data as required to meet the objectives of the program.
- Complete trust by the team members that all efforts will be made to achieve the goals of the program. This also encompasses teaming member's internal organization in regards to the technical leads communicating freely outside their organization.

These key characteristics of the EO-1 program were inherent in the program from inception. Program managers from the teaming organizations agreed on the mutual scope of the organizations involved and provided uninhibited communication between the organizations. This management philosophy facilitates a quick response to changes in customer requirements, which is mandatory for satellite programs that incorporate new technologies or are unique in mission design.

Spacecraft Bus Development Team Organization

The successful re-configuring of EO-1 to meet the schedule and cost constraints was aided by the organizational structure of the EO-1 design team. EO-1's program organizational structure facilitated an environment where there were no communication boundaries between organizations. This organizational structure was spawned from the EO-1 management concept discussed above.

Figure 3 provides a top-level overview of the Mission Team and their respective responsibilities. GSFC is responsible for mission management, operations, and launch vehicle procurement. GSFC also provides the design leads for the Wide Band Array Processor (Solid State Recorder), Global Positioning System, and X-Band Phase Array Antenna.

The Spacecraft Bus development is lead by Swales Aerospace. The other major Spacecraft Bus team participants included Litton Amecom, the Hammers Corporation and Welch Engineering. Additional team members, which provided subsystems were TECSTAR Inc. and PRIMEX Corporation. Although the Spacecraft Bus team members have extensive experience in designing, building and testing flight hardware, the EO-1 program represented their first endeavor into multi-system level integration.

The Spacecraft Bus design development team is shown in further detailed in Figure 4. The technical leads for both Swales and Litton Amecom teams are fully committed to the EO-1 program from the concept phase to the launch campaign. This Core Team philosophy reduces the amount of information transfers between the different phases of the program allowing for a more efficient use of resources.

Of special note is the assignment of the Litton Program Manager (PM) as a deputy PM to the Swales PM. Swales selected this structure to facilitate communication between all parties; particularly between GSFC and Litton. The development of the Avionics, which Litton was responsible for, was being co-developed with the GSFC MAP program. Swales wanted to assure that there was a direct communication link between GSFC and Litton Amecom.

The EO-1 organizational structure dictated the team meeting schedule on the program. The weekly GSFC EO-1 project staff meetings included both Swales and Litton Amecom Program Managers. In addition, meetings between Swales, Litton Amecom, the Hammers Corporation and Welch Engineering occurred each week at both Swales and Litton Amecom facilities. These meetings also included GSFC representation. This proliferation of meetings facilitated communication between the team members allowing for problem resolution and quick decision making.

Both Swales and Litton Amecom Program Managers encouraged communication between their respective technical leads. The GSFC representatives were also allowed free access to the technical leads from each organization. This communication network was facilitated by the organizational structure and allowed for a quick response throughout EO-1 development.

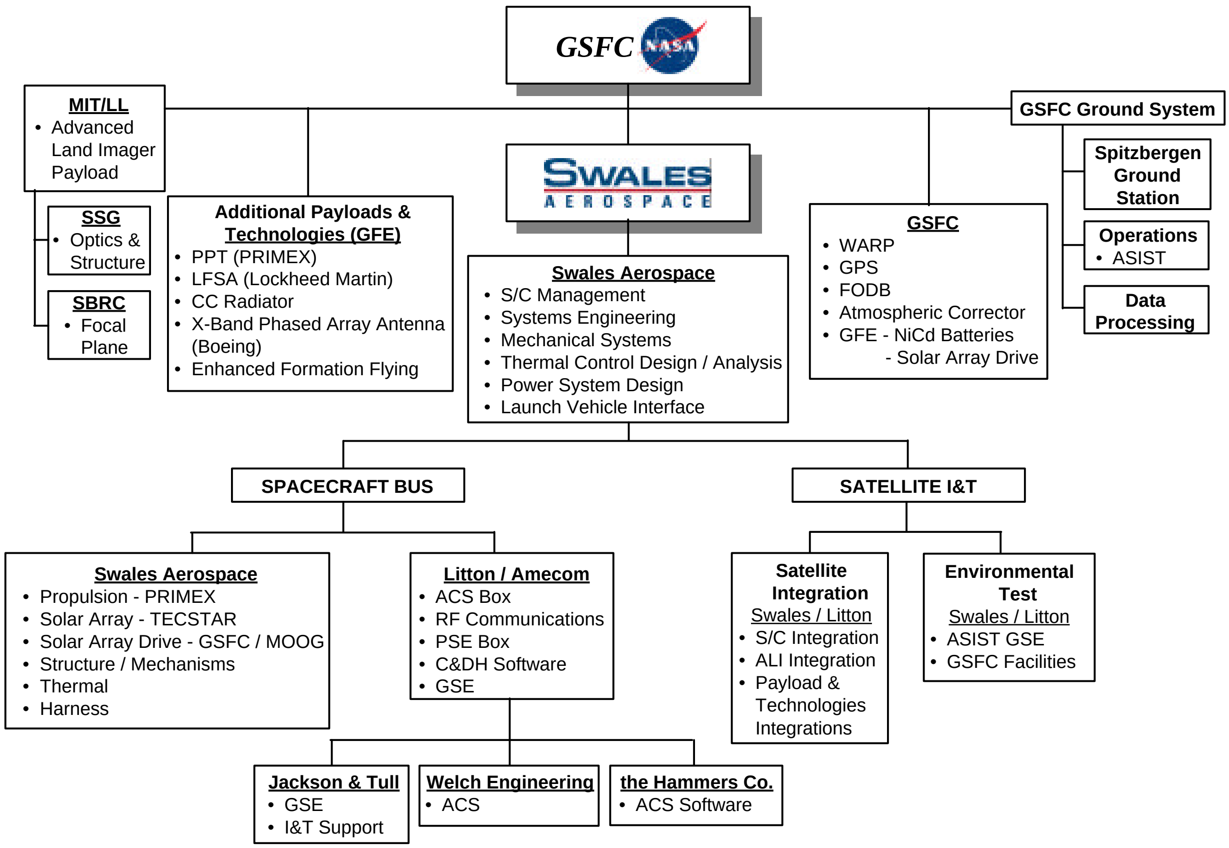


Figure 3 Overview of Mission Team

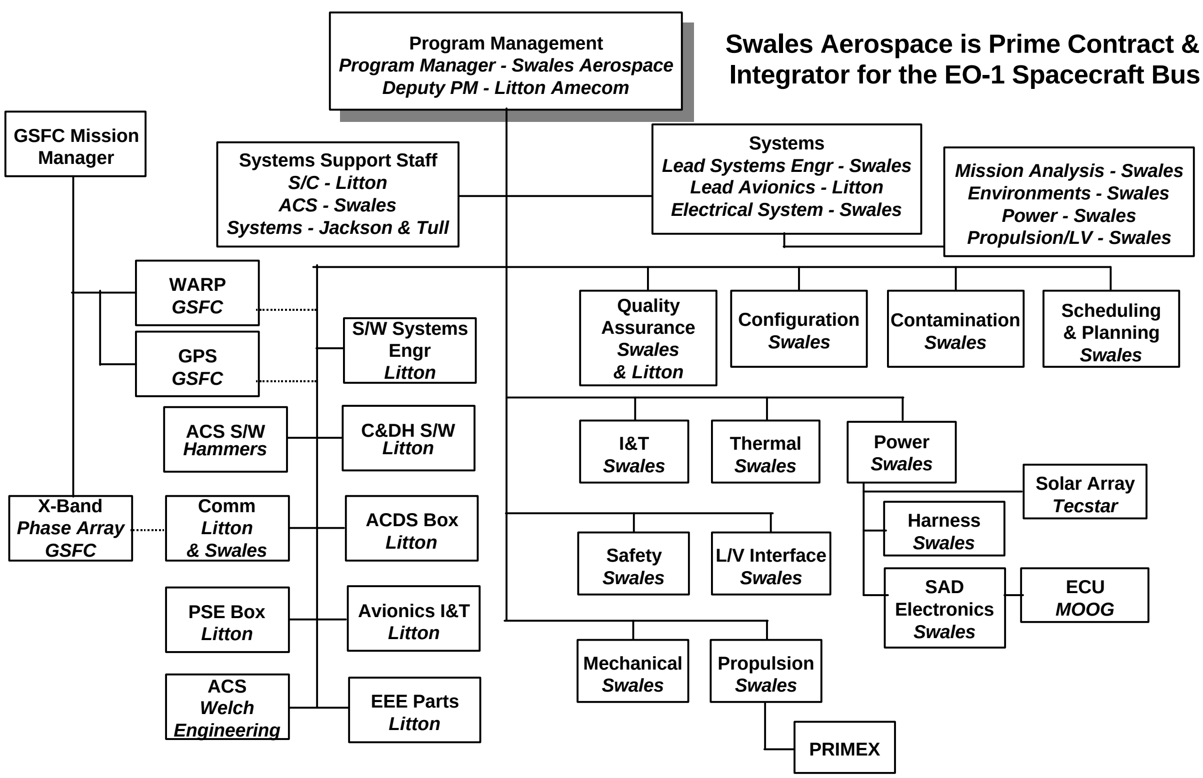


Figure 4 Spacecraft Bus Development Team

Satellite Integration and Test Team Organization

The evolution of the EO-1 organization for the Integration and Test phase of the program closely resembles the Spacecraft Bus Development team as shown in Figure 5. The Litton Amecom design team and its subcontractors are fully assimilated into the Swales team. The Deputy I&T manager is a Litton employee and reports to the Swales I&T manager. This organization will be carried forward to the Launch program. During the Spacecraft Bus I&T phase, all team members will be co-located at Swales Aerospace, Beltsville, Maryland facility. The software development lab will also be located in close proximity to the I&T activity to allow for expedient checkout of software modifications. Following Spacecraft Bus I&T, the program will be moved to GSFC for environmental test and all personnel directly responsible for testing will be co-located at GSFC.

Due to the aggressiveness of the I&T schedule and the potential for late deliveries of the technologies, a detailed assessment of the hour by hour operations of I&T was performed. A tiger team was then brought together that consisted of GSFC, Swales and Litton Amecom personnel to evaluate the credibility of this schedule. The team also pulled in GSFC personnel who had extensive knowledge of I&T and worked recent programs at GSFC. The team came up with a number of risk mitigation methodologies to address potential late deliveries. This effort again reflects the flexibility and agility of the EO-1 organization to address potential problems before they impact the program.

The GSFC Fight Operations Team (FOT) will also have several members assimilated into the Swales/Litton team during Spacecraft Bus I&T. This opportunity will be valuable for the FOT to get familiar with the satellite software and hardware interfaces. The FOT will also establish interfaces with the GSFC Mission Operations Center (MOC) early in the program.

The I&T team and FOT organization will use the GSFC developed Advanced Spacecraft Integration and System Test (ASIST) software to communicate with the spacecraft. ASIST provides real time command and control for spacecraft control system applications. It will be configured to store the complete I&T command and telemetry history for EO-1. ASIST was chosen by the EO-1 team to fully integrate the I&T team and FOT team so that minimum effort was required to transition to flight operations. Using a common software language reduces schedule, risk and overall cost to GSFC. This decision was jointly agreed upon early on by GSFC, Swales and Litton Amecom. This agreement on the use of ASIST is consistent with EO-1 Management Concept described above that uninhibited communication would be the norm on the program.

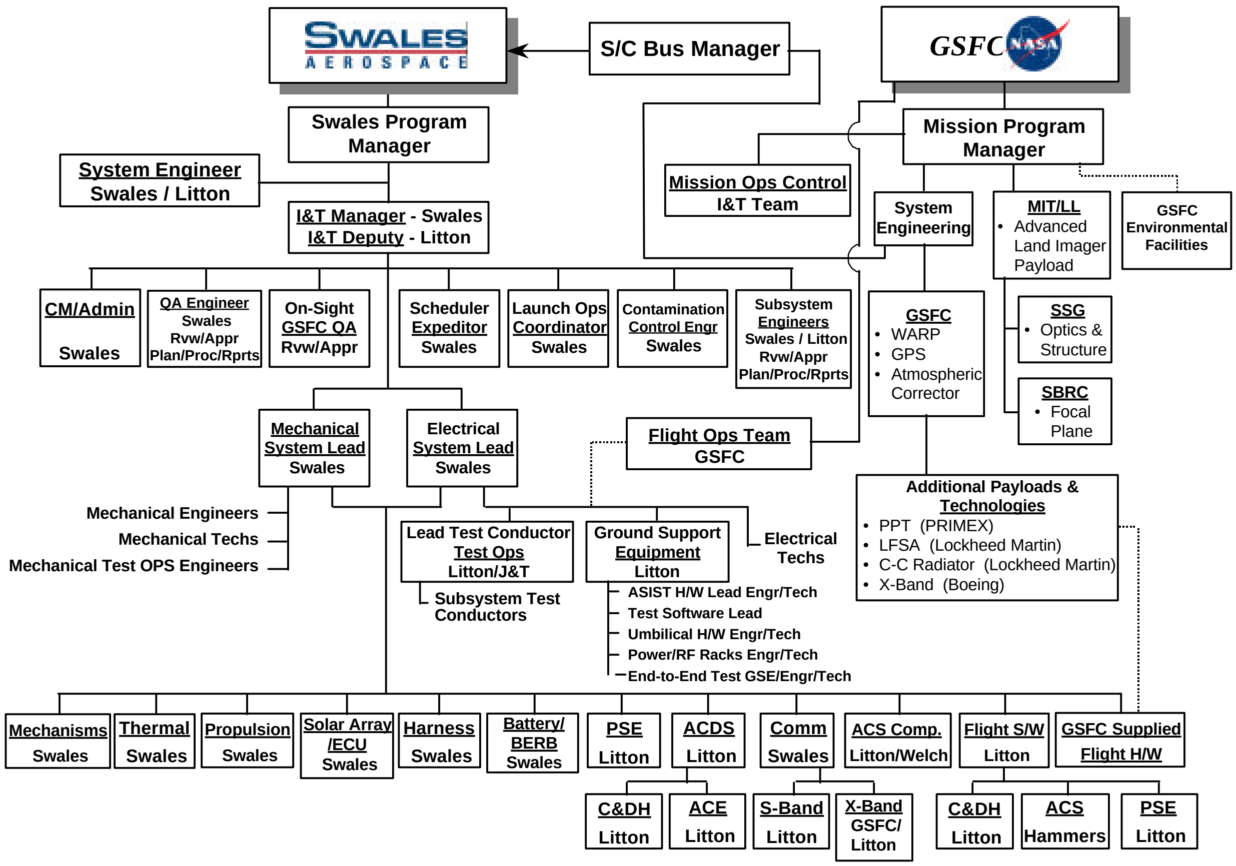


Figure 5 EO-1 I&T Team

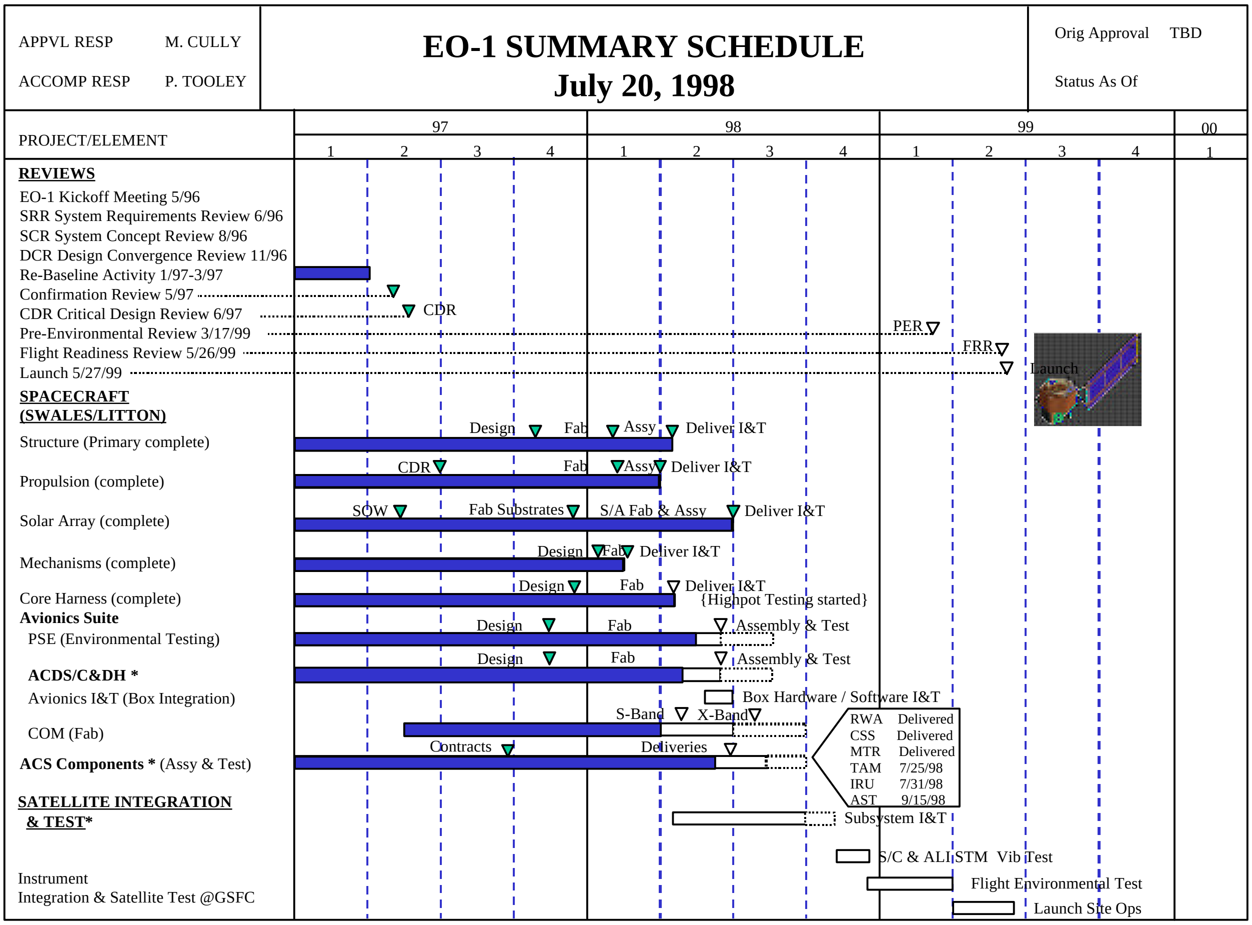
EO-1's Early Challenges

The EO-1 summary schedule is provided in Figure 6. From inception, the EO-1 program incorporated an aggressive schedule with 36-months from the initial concept to launch. Meeting this schedule is compounded by the fact that a number of the new technologies, which are currently part of the baseline were not selected until five months into the schedule. Further, the requirements of the program were in a state of flux due to the complexity of balancing what performance the technology could achieve versus the scientists' desires.

The original EO-1 program concept incorporated only those technologies, which were embedded in the Advanced Land Imager (ALI). As part of the New Millennium program, administered by Jet Propulsion Laboratory, approximately two dozen other technologies had to be evaluated for inclusion into the program. Several months of evaluation by the EO-1 development team culminated in a down select of eight additional technologies from the original set in September 1996. A more detail concept study of the satellite configuration began shortly thereafter to determine the impacts to the baseline program.

Following the new technology insertion phase a Design Convergence Review (DCR) was held in November 1996. This review was equivalent to a Preliminary Design Review with multiple paper deliverables showing the feasibility of accommodating the new technologies.

After DCR, a re-baseline costing captured the costs for accommodating these new technologies. This re-baseline costing was submitted to GSFC in January 1997. The re-baseline costing exceeded the cost cap imposed on the EO-1 program, which triggered an intense effort to reduce cost on the program. Coupled with this activity, GSFC directed the spacecraft team to accommodate a significantly tighter pointing requirement and a change in the launch vehicle. These two changes further exacerbated the cost problem.



*** Critical Path**

Figure 6 EO-1 Summary Schedule

The EO-1 team spent approximately three months to re-configure the spacecraft to meet the cost cap and the new imposed requirements. This redesign required tremendous effort by all the primary team members which included GSFC, MIT/LL, Swales Aerospace, Litton /Amecom, and Welch Engineering.

The March 1997 re-baseline effort incorporated the following major changes to the EO-1 program:

- The launch vehicle changed from a Taurus XL to the Delta 7320 with a 10-ft. diameter fairing. This change provided the opportunity to perform mass and cost trades.
- The primary structure was changed from an all composite to an all aluminum structure to reduce cost. This change also allowed a reduction in schedule since material lead times and fabrication time were decreased.
- A Star Camera-based attitude determination system was implemented replacing the Fine Sun Sensor and Magnetometer based pointing system. This allowed pointing accuracy to improve from 0.25 degrees to 0.022 degrees.
- The batteries were changed from NiH2 to NiCd to reduce overall cost since the NiCd could be furnished by GSFC (TRMM flight spare). Some of the cost savings were offset by the redesign of the spacecraft primary structure due to the significant increase in mass and size of the NiCd.
- Consolidated the software development facilities to reduce cost and improve communications between the software teams.
- Designed the primary and secondary structures, where appropriate, to higher factors of safety (No Test Factors) and higher loads. This was again a mass versus cost trade, which was afforded by the change in the selection of the Delta 7320. This also had a positive impact on the mechanical development schedule since it reduced the structural testing phase of the program.

- Re-configured the nadir S-Band antenna boom to be a fixed antenna system. The previous design incorporated a deployable boom. Although this increased mass the fixed antenna system was less complex and therefore more reliable.
- The Solar Array release system was changed from a Frangibolt design to a High Output Paraffin (HOP) actuator design. This increased reliability by providing mechanical redundancy. This design also shortens the mechanical test schedule due to the inherent simple reset capability of the HOP actuator.

The new baseline was established in late March of 1997 with a start of detail design in April 1997. A Critical Design Review was held in June of 1997 with fabrication starting shortly thereafter. The effective schedule for the EO-1 program went from 36 months to approximately 27 months. This is extremely aggressive since a large percentage of the hardware was new development (Power Supply Electronics, Attitude Control and Data Handling, Solid State Recorder, Advanced Star Tracker, etc.).

A major re-baseline within three-months indicates the flexibility and quick response of the EO-1 team. This quick response by the EO-1 team was attributed to excellent systems engineering and superior communication between the team members facilitated by the program's organizational structure.

Subcontract Interfaces in Firm Fixed Price Environment

In order to stay within the strict cost constraints of the program, a Firm Fixed Price (FFP) contract for the Spacecraft Bus was negotiated between GSFC and Swales Aerospace. FFP contract vehicles were established for all subcontractors requiring detail Statements of Work (SOW) and clear specifications.

All the subcontractors were given maximum latitude in the use of best aerospace commercial practices, defined as those practices, which are currently being successfully employed on existing aerospace commercial programs. ISO9001 was the quality standard for a large percentage of EO-1 suppliers. The Product Assurance requirements imposed on the subcontractors provided flexibility, but did not compromise oversight by Swales Aerospace or GSFC. Mandatory inspection points were imposed at selected points in the development program. A rigorous Pre-ship Review was held at each major subcontractor to assure that all documentation was in order.

In a number of cases, costs were minimized by Swales providing structural components which were on critical path at Swales subcontractors. Cases in point are PRIMEX Corp. on the propulsion module and TECSTAR Inc. on the Solar Array. Swales provided the Zenith Deck to PRIMEX for the integration of the Propuslion Module. Swales provided to TECSTAR Inc. the Solar Array Panel substrates, flight mechanisms, ground support test equipment and engineering services to support the full integration of the Solar Array at their facility. The subcontractors would then do the subsystem integration and test. Engineers from Swales Aerospace supported the test program as required. This served two purposes: first it allowed the Swales Aerospace engineers to become more familiar with the particular subsystem, reducing the amount of integration time at the Spacecraft Bus level; and it reduced some of the labor costs at the subcontractor. This approach was implemented at various times in the development of the Avionics subsystem, Solar Array integration and Propulsion subsystem.

This approach was not confined to Swales Aerospace but was also implemented in other subcontractor relationships on EO-1. GSFC provided several critical components (i.e. X-Band Antenna, NiCad battery, GPS, Solid State Recorder, etc.) and labor resources to reduce the schedule and therefore the cost to the overall program. Further, GSFC provided Flight Operation Team (FOT) members as test conductors during the Avionics integration and test campaign. FOT members gained valuable knowledge on the operation of the flight hardware and software long before the Spacecraft Bus testing program started. The Avionics testing team was also supplemented with valuable test conductors.

An important contribution to the EO-1 team in bringing together the partnering relationships was due to the Subcontract Management function. The traditional role of the Subcontract function has been to control the contract relationship to the benefit of the parties being represented. On the EO-1 program Subcontract Management (GSFC, Swales, Litton Amecom, TECSTAR, PRIMEX) played a vital role in fostering a teaming environment so that the goals of both parties were achieved. Communication between Prime and subcontractor was allowed to occur within a broad spectrum so that both sides of the contract could react quickly to problems. In typical organizations, the Subcontract function will error on the side of total control over communication, which tends to slow down the development process in a concurrent engineering environment.

Use of Electronic Media

A significant component of cost control on EO-1 was the heavy reliance on electronic media between all organizations involved. Electronic mail is the main media between EO-1 team members. FTP sites were established to facilitate the transfer of large CAD and analysis files.

Industry and Government Alliances

Strong industry-government alliances have played a significant role in the execution of the EO-1 Program. Litton Amecom and the Goddard Space Flight Center entered into a Space Act Agreement at the initiation of the program to provide a structured mechanism for the transfer of NASA MIDEX technology upon which the EO-1electronic subsystems are based. Litton Amecom worked within an Integrated Product Team along side their GSFC counterparts to support the development of hardware and software designs for the Microwave Anisotropy Program (MAP). The EO-1 designs were then adapted from the MAP designs to satisfy EO-1 mission requirements. Litton Amecom engineers became familiar with NASA MIDEX technology by working with GSFC developers on the MAP spacecraft while simultaneously augmenting the MAP design team with Litton Amecom-funded engineers

Under the auspices of the Space Act, Litton Amecom engineers supported GSFC development of the MIDEX Power Switching Electronics (PSE), Attitude Control and Data System (ACDS) electronics, Command and Data Handling (C&DH) software, and the government furnished EO-1 Wideband Advanced Recorder/Processor (WARP). The close working relationships, developed as a consequence of the Space Act, also yielded additional benefits to both programs. Examples include a common parts buy program, common EEE parts screening requirements and coordinated technical monitoring for common subcontracted hardware components and long lead parts. However, the most significant benefit resulted from the planned evolution of MAP designs intended for future commercialization. These designs, with flight heritage that extended back to the late 1980s, were updated to incorporate the strategically Rad Hard Mongoose V 32 bit RISC processor, table look-up modifiable software, plug and play standard 1773/1553 interfaces, and modularity and scalability features that made EO-1 adaptations relatively simple. Litton Amecom credits GSFC for their vision of a truly adaptable spacecraft avionics architecture that could be applied to almost any new mission without having to sacrifice performance for cost and size.

The success of the Space Act Agreement can be measured not only in terms of its contribution to the success of EO-1, but also the realization of GSFC's vision of a new spacecraft architecture that could benefit the space industry and Litton Amecom's goal of commercializing this technology.

Effective industry partnerships are also important to the success of the EO-1 program. Swales Aerospace, the prime contractor for EO-1, and Litton Amecom, the avionics subcontractor, rely upon the support of several small local businesses which have played key roles in the design and development of EO-1. Welch Engineering, Ltd. and the Hammers Company provides essential expertise and services in the areas of attitude control analysis and software design, respectively. Representatives from each of these firms are considered full team members, and are extended the same degree of design responsibility and authority for their content as Swales and Litton Amecom. The extent of this intimate working relationship is further evidenced by the fact that employees from Welch and Hammers fill lead positions in the EO-1 organizational chart.

These achievements clearly demonstrate the merits of the Space Act to industry and the government. A true win-win relationship has resulted in which the space industry and the Government have both benefited from a partnership to provide a better product.

Near Term Challenges to the EO-1 Team

NASA GSFC has requested that the EO-1 Team assess the feasibility of integrating the Hyperion Imaging Spectrometer (HIS) on the EO-1 Spacecraft Bus. This accommodation will require the placement of the HIS and two other components on the Nadir deck. This will increase the mass of the spacecraft by at least 10% and require modifications to a number of subsystems. Early indications are that there are no major stumbling blocks and it is expected that the feasibility study will be completed by late September 1998. This challenge will once again test the EO-1 team’s flexibility and customer responsiveness.

Summary

The EO-1 program represents a new way of doing business and is anchored on the premise of mutual respect for the teaming members involved. The Small Satellite market place in the New Millennium will require building these types of relationships in order to build a program team that is flexible, technically competent and quick to respond to the customer needs.

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